Managing capabilities for research centers in the UK's manufacturing sector: from literature review to a conceptual framework

Olga Uflewska
Department of Design, Manufacture and Engineering Management,
University of Strathclyde,
Glasgow, 75 Montrose St, Glasgow G1 1XJ, UK
olga.uflewska@strath.ac.uk

T.C. Wong
Department of Design, Manufacture and Engineering Management,
University of Strathclyde,
Glasgow, 75 Montrose St, Glasgow G1 1XJ, UK
andy.wong@strath.ac.uk

Michael Ward
Advanced Forming Research Centre
85 Inchinnan Drive, Inchinnan,
Renfrewshire, PA4 9LJ, UK
michael.ward@strath.ac.uk

Abstract

This study uncovers the knowledge gaps regarding the capability management of research centers in the UK manufacturing sector. The paper presents some key findings from systematic literature review and introduces a novel framework that will improve the decision making process related to capability development and strategy building which are the two main challenges for the UK manufacturing research centers. The findings presented in this paper highlight the need for and the key elements of such a framework and the benefits that it will bring to a research center's capability management, e.g. more effective evaluation of capabilities and comprehensive understanding of development of those capabilities. It also identified knowledge gap related to management of technology capability from a research centre perspective. At the moment there is a lack of standardized framework (or approach) that is easy to use and applicable to research centres in the manufacturing sector. The paper presents findings from systematic literature review and introduces a novel framework that will improve the decision making process related to capability development and strategy building in the manufacturing research centers.

Keywords
Capability Management, Research Centers, Operations Management, Decision Making, Strategy

1. Introduction
For the purposes of this study, research centers are considered to be buildings, facilities, and coordinated teams focused on a particular area of development. They are distinct from research institutes in that they are a target a specific area of work, which is typically somewhat applied. The main focus of this paper is on independent (i.e. separate form any single company) translational research centers (ITRCs), i.e. those which are focused on addressing the gap between proof of concept (typically the end point for mainstream academic research), and

industrial application. Examples of ITRCs are the Fraunhofer centers in Germany, and the High Value Manufacturing Catapults centers in the UK.

Research centers are very important, especially in the manufacturing sector, as their main purpose is to bridge the gap between academia and industry. Hence, their aim is to "overcome modern engineering issues such as 'valley of death'" (Uflewska et al., 2017), and "to close the critical gap between research findings and their subsequent development into commercial propositions" (Hauser, 2014). However, in order to go through that transition successfully, it is necessary for a research center to recognize its own capabilities (i.e. strengths and weaknesses), and which of them are matured enough in order to call a research center an expert (in a specific technology/processes). Research centers need to respond quickly to industrial client needs, which imply the existence of a level of an underlying capability (i.e. strengths and weaknesses) in selected key areas, ahead of the launch of a specific project to address a particular implementation.

Therefore, in this paper, capability is defined as "a skill to carry out the deployment, the combination and the coordination of resources and competences through various value flows to put in work the strategic objectives beforehand defined" (Booto Ekionea et al., 2007).

In order for manufacturing research centres to "turn ideas into commercial applications by addressing the gap (valley of death) between technology concept and commercialisation" (HVM Catapult, 2018), they need to have an objective approach that will allow them to understand their capabilities (i.e. strenghts and weaknesses). Furthermore, exsitisng frameworks do not apply to (and do not address) research centres needs (and challenges). They are usually too vague and time-consuming, which also makes them impractical in a research centre environment (Uflewska et al., 2017). Hence, in order to enhance modern innovation providers, a new conceptual framework is proposed. The framework concentrates on work and vison of research centres and is created to address their particular challenges realted to technology and strategy development, as well as decion making process.

2. Results

2.1 Seven research themes

This systematic literature review focused on 118 papers from 15 well-established journals dedicated to manufacturing and management. The process involved clearly defined steps which are repeatable and transparent. The steps were also based on the systematic assessment performed by (Wetzstein et al., 2016). The systematic literature review identified seven key research themes. Each research theme was also divided into sub-themes. Those results are presented in Table 1.

Table 1. Research themes identified in the SLR

	Research Themes (RT)		Sub-themes (ST)
RT1	Challenges	1a	what external factors affect company
		1b	types of challenges
RT2	Maturity	2a	of product/technology/process/industry
		2b	what kinds of maturity affect manufacturing
		2c	maturity models
RT3	Capabilities & Performance	3a	development of capabilities
		3b	types of capabilities
		3c	how capability affects performance
		3d	knowledge & information transfer
		3e	technology transfer
		3f	socio-technical systems
		3i	innovation
RT4	Strategy	4a	importance of strategy
		4b	definition of strategy
		4c	manufacturing tasks & strategy
		4d	impact of strategy on company/strategy & performance
RT5	Decision making process	5a	importance of DM
		5b	decision makers/managers/who is a good decision maker?
		5c	what influences DM process
RT6	Supply chain aspect	6a	definition

		6b	importance for manufacturing sector
RT7	University-industry collaboration	7a	academic perspective
		7b	manufacturing companies' perspective
		7c	importance of R&D centers

However, considering the amount of articles dedicated to each research theme, it could be stated that some of the research themes happened to be examined more often than others. For example, various aspects of capabilities (development and types of capabilities in different organizations) were described in 52 papers (44% of total number of papers), while only 8 papers (e.g. 6% of total number of papers) described the importance of supply chain. That is easily explained by the systematic review process, which was performed by the use of specific keywords. Furthermore, this SLR process emphasized three most discussed RTs/STs, as presented in Table 2 below.

Table 2. Main three RTs/STs in the SLR

Research themes	**Number of articles that included RT/ST**	**Percentage of articles discussing specific RT/ST**	**Number of times RT/ST was discussed throughout the SLR**
Types of capabilities	52	44%	100
Types of challenges	48	40%	113
Decision makers/managers/who is a good decision maker?	42	35%	62

As those were the most examined research themes throughout the SLR, next step involved focusing on those sub-themes and investigate how they affect work of an organization.

2.2 Research centres

(Hauser, 2014) highlighted "the need for the UK to close the critical gap between research findings and their subsequent development into commercial propositions." Thus, main purpose of research centers is to develop appropriate capabilities and to put them in place in order to close that gap (i.e. valley of death). For that reason, UK government established High Value Manufacturing Catapult network which involved "physical centres with associated technical know-how generally operate in the middle levels of technology readiness and provide services that address market failures, which in particular impact heavily on capital investment by firms, and tend to pay off over longer timescales" (Hauser, 2014). Figure 1 shows the connection between research centres, large companies and academia, as well as indicates at what stage of technology development (i.e. Technology Readiness Levels) research centres are placed.

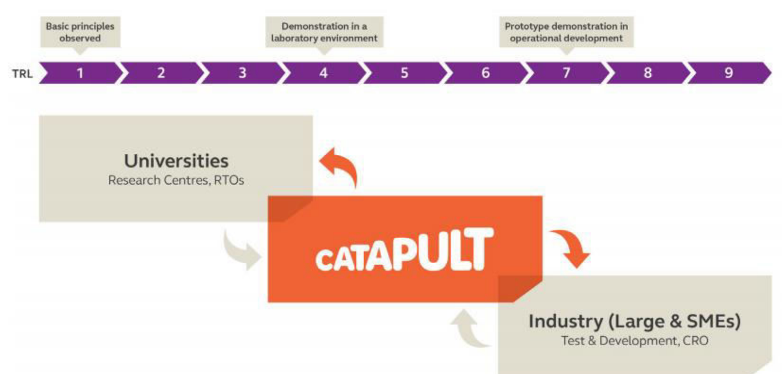

Figure1. Relationship between academia, research centres and industry (Hauser, 2014)

2.3 Challenges & Decision Makers

The challenges related to capability management in various organizations are grouped into two categories: external and internal challenges. External challenges are identified as factors, such as: megatrends, quickly changing market, customers' requirements (Lee & Kang, 2017), (Machado, de Lima, da Costa, Angelis, & Mattioda, 2017), (Kalkan, Bozkurt, & Arman, 2014), (Mikkola, 2001), (Koufteros, Vonderembse, & Doll, 2002), (Drejer & Riis, 1999), (St John, Cannon, & Pouder, 2001), (Druilhe & Garnsey, 2004). On the other hand, internal factors are, for example:

understanding companies own capabilities, choosing suitable long and short term strategy, organizational complexity, design of suitable operations, risk management, uncertainties management, uncertainties in regards to ability for technology (product) to be transferred to next level, as well as lack of time for managers to analyze necessary requirements for suitable strategy building and lack of analytic capabilities i.e. how to include competence based thinking in decision making/inexperience managers (Fuchs, Mifflin, Miller, & Whitney, 2000), (Machado, de Lima, da Costa, Angelis, & Mattioda, 2017), (Mikkola, 2001), (St John, Cannon, & Pouder, 2001), (Boon-itt, Wong, & Wong, 2017), (Srivastava & Gnyawali, 2010), (Tu, Vonderembse, Ragu-Nathan, & Sharkey, 2006).

Therefore, above challenges are directly or indirectly link to capabilities and the level of development that company's capability is at. Hence, decision makers (i.e. usually senior members of staff) have a responsibility to observe external and internal changes. Based on those changes, the internal capabilities might change from strength to a weakness (or other way around), and a new strategy will have to be developed. That only confirms how important it is for decision makers to have analytical skills and also have enough time to observe, assess and act based on the relevant information.

Other challenges that were identified through SLR, and which are related to the work and responsibilities of decision makers are presented in Table 3.

Table 3. Challenges related to decision makers

Challenge	Example from literature	References
Identification of opportunity	"The first difficulty facing academic entrepreneurs is to identify and select a viable productive opportunity. Opportunities are objectively identifiable but their recognition is subjective and often depends on access to special knowledge"	(Druilhe & Garnsey, 2004)
	"Developing the "right" new products is critical to firm success and is often cited as a key competitive dimension (Roussel et al. 1991, Cooper et al. 1998). Companies that make poor choices with respect to their new product development (NPD) portfolio run the risk of losing their competitive advantage."	(Raul & Stylianos, 2008)
Utilization of knowledge/Complexity of operational systems/tools	"Managers face difficulties not in accessing knowledge, but in utilizing knowledge in decision making and in embodying knowledge in products/services and processes."	(Soo, Devinney, Midgley, & Deering, 2002)
	"Managers need models that help them understand the organizational and environmental antecedents and outcomes of detailed but uncomplicated classifications of learning and knowledge"	(Herrmann, 2005)
Uncertainty & uncompleted information	"Making decisions under uncertainty and with incomplete information requires decision makers to draw inferences about future events"	(Nerkar & Paruchuri, 2005)
	"Information inadequacy can arise from both project ambiguity and project complexity. Ambiguity refers to a lack of awareness of the project team about certain states of the world or causal relationships (Schrader et al. 1993). Project complexity means that many different actions and states of the world parameters interact, so the effect of actions is difficult to assess"	(Pich, Loch, & De Meyer, 2002)
Capturing relevant information	"To compete successfully, managers need to be able to scan their environments, identify relevant opportunities and threats, to design responses that will satisfy customers in ways that competitors can't easily imitate, and, finally, to ensure that these plans are implemented (…). Yet, capturing and distilling relevant information isn't a natural capability for most senior management teams"	(Harreld, O'Reilly, & Tushman, 2007)
Communication	"The most sophisticated analyses in the world are worthless if findings cannot be communicated to decision makers in ways that will encourage their use. Likewise, if decision makers cannot communicate their needs to analysts, modelers, and outcome managers, or if database administrators cannot communicate with data modelers for that matter, then the entire data-to-knowledge process is at risk. A director of decision support for a consumer goods company says his biggest problem is getting business analysts to present their findings to product managers in ways that they will be understood and accepted as useful."	(Davenport, Harris, De Long, & Jacobson, 2001)
Evaluation of skills, capabilities and resources	"Managers of firms seeking to build analytical capabilities must evaluate the level and structure of skills needed to support their organization's data analysis capabilities. If the skill levels of the business analysts, data modelers, and decision makers in an organization are inadequate, then a firm cannot be getting full value from its transaction data."	(Davenport, Harris, De Long, & Jacobson, 2001)

	"Knowledge management sits well within our understanding of what drives change and motivates innovation. This creates a convenient solution for managers trying to deal with the intangibility of knowledge. Most critically, managers can measure the change in innovative outputs that flow from knowledge management strategies and practices".	(Soo, Devinney, Midgley, & Deering, 2002)

Therefore, based on the information presented in Table 3, it is possible to see that decision makers have to struggle with a variety of challenges. Some of them refer to "intangibility of knowledge" (Soo, Devinney, Midgley, & Deering, 2002), or "utilizing knowledge in decision making and in embodying knowledge in products/services and processes" (Soo, Devinney, Midgley, & Deering, 2002). And so, as (Herrmann, 2005) mentioned decision makers "need models that help them understand the organizational and environmental antecedents and outcomes of detailed but uncomplicated classifications of learning and knowledge."

That is why decision makers from research centers need a tool that will help them evaluate and understand how well developed their capabilities are, and to overcome already mentioned challenges.

2.4 Existing methods/tools

Exisitng methods are mostly based on Technology Readiness Levels (TRL) measurement system or on Capability Maturity Model (CMM). Both methods (and other methods beased on those two) are not applicable in a research centre environemnt. Table 4 shows examples of those methods and explains the reasons why they are not suitable for research centres.

Table 4. Comparison of different performance tools/methods

Tool/Method	Usage	Disadvantages
Capability Maturity Models (CMM)	"Capability Maturity Model™ (CMM™) (…) Based on the specific software practices adopted, the CMM classifies the software process into five maturity levels. (…) "Maturity levels were associated with a software product based on the maturity level of the IT firm at the beginning of a product's design. The maturity level of a product that benefited from process improvements later in the product's life-cycle stages (e.g., coding stage) was assigned a commensurate increase in maturity level." (Bititci, Suwignjo, & Carrie, 2001)	"Such tool has to be adjusted to the needs of specific industry and addresses common problems that affect multiple actors" (Uflewska et al., 2017) Developed for software industry, highly advanced and complex- too complex for smaller organisations
People Capability Matutiry Models (P-CMM)	"The P-CMM framework which is a roadmap for implementing management processes and practices in order to continuously improve the capability and productivity of the human resources and to execute the strategic objectives of the organization" (Kropsu-Vehkapera & Kess, 2013)	Developed for universities, only involves human aspects
Technology Readiness Levels (TRL)	TRLs are "a type of measurement system used to assess the maturity level of a particular technology" (NASA, 2012). It is used to underatnd • On what level different technologies are currently • What level of each of those technologies we need in order to develop one specific system	It does not imply that the technology "will result in successful development of the system" (Nuclear Decommissioning Authority, 2014,) "It adds a degree of unnecessary ambiguity to a project, i.e. not accurate enough for some projects It does not apply to system integration" (Uflewska et al., 2017)
Manufacturing Readiness Levels (MRL)	"It assesses the development of a particular technology from a manufacturing perspective. It brings structure, but also helps to monitor how different aspects of technology are being developed" (Uflewska et al., 2017)	"It describes today's position, without providing close support (…) in how to plan or execute a specific project or lower level task" (Ward et al., 2012)
Manufacturing Capability Readiness Levels (MCRL)	(House of Commons, 2013) presented this nine-point scale as: "MCRL 1-4: Conception and assessment of Manufacturing Technology MCRL 5-6: Critical 'pre-production' phase, where expensive full-scale equipment and processes must be used but ahead of product launch , or factory MCRL 7-9: implementation of the process on the shop floor, and also confirms volume production with assured quality"	•In relation to MCRL 4-6: "investment is high, but there is no certainty that (…) the proposed process will be successful" (House of Commons, 2013) •Size of the framework is overwhelming and it is time-consuming

In order to manage capabilities, an appropriate management tool/method has to be put in place. Different companies will use various tools depending on the nature of business and organizational structure of a company. Therefore, most industrial tools have been specifically designed according to the needs and type of work of a company.

As discussed before those approaches are complex, time consuming and very often created with a specific purpose in mind (e.g. to be used with certain criteria that are applicable to a company that created the tool). And makes them inapplicable in research centres. Those tools are created considering vision and specific operations of a company in order to deliver high quality products and services. However, innovation providers differ from manufacturing companies as they do not have a large and complex organizational structure, and they mainly focus on addressing the gap between proof of concept (typically the end point for mainstream academic research), and industrial application (HVM Catapult, 2018). It means that a capability assessment for a research center should be much simpler and less time consuming, i.e. it should only consider most important capabilities that will have influence on all the projects. By doing so, a decision maker will be able to recognize research center's strenghts and also areas that need further attention. That will help with minimizing risks (during projects) but also building a suitable long term strategy. In addition, evaluation of tangible and intangible capabilities will bring additional benefits, e.g. simplifying decision making process and understanding what capabilities are needed for a research centre to grow.

3. Discussion

3.1 Capabilities

Previous sections explained the work and importance of research centres, as well as challenges that are related to decision makers. Those challenges are also related to the fact that research centres currently do not have a tool that is applicable to all manufacturing research centres (e.g. HVM Catapults in UK) (Uflewska et al., 2017). It is due to the fact that none of the existing tools concentrates on the needs and issues that modern research centres are facing. Exciting tools are usually too complex and time consuming. Also they usually concentrate on newness of a product, but do not consider if a research centre actually has the capability to develop that particular product.

The previously introduced definition by (Booto Ekionea, et al., 2007) highlighted that capability is "the combination and the coordination of resources and competences." In this research, resources are referred to as tangible capabilities (which are also quantitative), and competences are referred to as intangible capabilities (which are qualitative). The difference between those two groups is discussed in next section. However, it should be recognized that both types of capabilities have to be assessed and managed in an appropriate manner in order to improve those capabilities and build better strategy, which is extremely important for HVM Catapults as their aim is to strengthen UK's manufacturing sector. Figure 2 shows the connection between those entities.

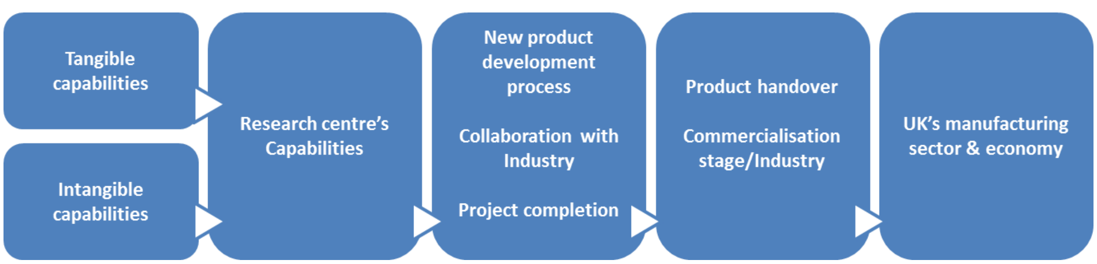

Figure 2. Impact process: how capabilities of research centre influence national manufacturing sector

3.2 Tangible and intangible capabilities

"According to the resource-based view (RBV), a firm's resources, particularly **intangible ones**, are more likely to contribute to the **firm's attaining and sustaining superior performance**" (Hsu & Wang, 2012). Hence, in order to achieve a status of an expert (which is relevant to research centers as they target a very specific area), an organization has to understand and manage its own intangible resources. And so, it is assumed that intangible capabilities have a more significant impact on organization's performance, than the tangible ones. On the other hand, an organization needs its tangible (i.e. basic) capabilities in order to use them to develop intangible once. Therefore, it is assumed that by keeping basic assets well-developed, it allows an organization to concentrate on expanding their intangible capabilities. The challenge is to measure, manage and develop those intangible capabilities, which still seems to be a very difficult task to many organizations, especially for research center, as there is no evidence in the literature of how research centers evaluate and coordinate their resources/capabilities.

It takes time for an organization to develop its own unique sets of capabilities (Wang & Ahmed, 2007). Building up capabilities could sometimes take years, but, in the end, an organization achieves certain level of expertise, which also has influence on its performance (O'Regan, Ghobadian, & Gallear, 2006), (Eddleston, Kellermanns, & Sarathy, 2008). Thus, by understanding and managing capabilities, an organization has an opportunity to improve its performance and develop its capabilities further. Hence, an organization realizes its strong and weak points and is able to recognize what types of projects should be involved in. Therefore, capabilities affect decision making process, strategy building and performance.

3.3 Conceptual Framework

Literature findings confirmed different issues in relation to capability management. They also showed a lack of knowledge in regards to the management of capabilities in research centers in the manufacturing sector. It also showed a gap in relation to work and responsibilities of research centres.

In order to fill the knowledge gap, a conceptual framework is proposed for the use of innovation providers. As presented in Figure 3 below, there are three main connections:

- Between strategy and tangible capabilities,
- Between strategy and intangible capabilities,
- Between tangible and intangible capabilities

The last connection was already described in previous sections. However it is important to highlight that both (tangible and intangible) capabilities will have influence on an overall strategy. According to (Harreld, O'Reilly, & Tushman, 2007) capabilities are "**a concrete set of mechanisms that help managers address the fundamental question of strategy**, which is to develop a truly sustainable competitive advantage. Interestingly, we are beginning to realize that sustainability is fleeting **unless it is aligned with capabilities** to continually sense how the marketplace is changing and seize these changes through dynamic organizational realignment."

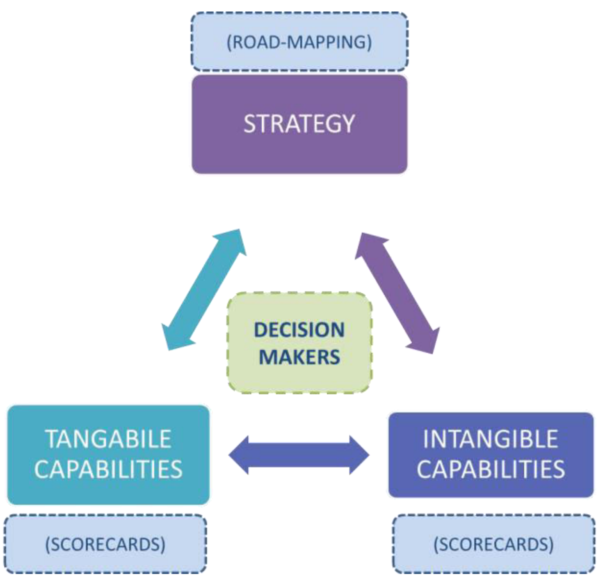

Figure 3. Conceptual framework for capabilities management for research centers in the manufacturing sector

Therefore, tangible and intangible capabilities have an influence on a short and long term strategy, but they also influence each other. However, by having an appropriate evaluation system, it will allow decision makers to fill in the results into the strategy (that is usually discussed by the use of road mapping process). Once the strategy is created it will feed back into the two types of capabilities in order to show the path that need to be created to improve those capabilities further. By assessing internal tangible capabilities it will be possible to achieve top level of performance in operations management. And by assessing intangible capabilities it will be possible to target a specific area of work, which will allow innovation providers to become experts in that area.

Tangible and intangible capabilities will be measured by scorecards. The scorecards have been created for both types of capabilities and they include all the capabilities that were discussed in previous sections. Due to the fact that tangible capabilities focus on operations, therefore the evaluation captures the quantitative aspects of those capabilities. On the other hand, the scorecards for intangible capabilities focus on capturing qualitative aspects that are difficult to quantify, but also because those are the capabilities that give innovations providers the expert status. The examples of scorecards are presented below in Figure 4 and 5 below.

TANGIBLE CAPABILITIES								
CATEGORIES	RESULT AREA	PERFROMANCE INDICATORS	FREQUENCY MEASUREMENTS (annually/quarterly/monthly)	VALUE MEASUREMENTS/UNITS	2014 DATA	CURRENT DATA	TARGET	PROGRESS
HUMAN CAPITAL		• Employee turnover/total number of employees		Numerical/percentage				
		• Ratio of engineers to the total number of staff		Numerical/percentage				
		• Ratio of engineers with industrial experience to total number of employees		Numerical/percentage				
		• Personnel cost		£				
		• Part time employees		Number				
	Employee satisfaction	• Job satisfaction		1-5 scale -> percentage				
		• Workplace safety		1-5 scale -> percentage				
		• Absence		%				
		• Training time		Hours/days per employee				
		• Training attendance		Number				
		• Difference in productivity before and after training		%				
		• Overtime		%				
		• Length of employment		Numerical/percentage				
		• Number of PhD/EngD students		Number				
EQUIPMENT	Machine 1/equipment 1 (repeated for different machines)	• Downtime		Number				
		• Time to repair		Number				
		• Mean time between repairs		Hours/days				
		• Repair costs		£				
		• Repair downtime		Hours/days				

Figure 4. Example of a scorecard for tangible capabilities

INTANGIBLE CAPABILITIES								
CATEGORIES	RESULT AREA	PERFROMANCE INDICATORS	FREQUENCY MEASUREMENTS (annually/quarterly/monthly)	VALUE MEASUREMENTS/UNITS	2014 DATA	CURRENT DATA	TARGET	PROGRESS
HUMAN CAPITAL	Competence	• **Continuous learning** • **Employees who execute their individual development plan** • **Average performance of new employees** • **Average performance of permanent staff** • **Efficiency of activities** • **New knowledge and competence** • **Research competence**		• Number/% • Number of intellectual property rights				
	Skills	• Qualified talents • Progress of Talent development		• Environment maximises employee productivity and performance • Number/% (actual vs. before)				
		• Customer base communication • Customer relationship management skills • Solution development practice		•				

Figure 5. Example of a scorecard for intangible capabilities

As an example a column with '2014 data' was included in the scorecard in order to indicate that capabilities will be measured continuously in order to show a history of development of a particular capability. By doing so, research centers will be able to track their capabilities and analyze what affected the development process. The framework aims to make the decision making process faster and more effective, but most importantly it allows to analyze capabilities of innovation providers and recognize what path will be the best for them at certain times. The framework will also help to capture potential uncertainties and risk related to internal operations.

4. Conclusions and Future Work

This study focused on a research gap presented by a literature in relation to capability management by innovation providers. The systematic literature review provided evidence confirming that existing capability management approaches are not suitable for modern innovations providers applicable due to their complexity and time that is required to fill in all the information. Hence, this research gap introduced an opportunity to create a novel framework that will shorten the decision making process as well as provide reliable justifications to explain at which stage of development a capability is at. SLR also presented the distinction between tangible and intangible capabilities that are key for different aspects of work. By using information from SLR, it was possible to identify the gap and create a conceptual framework for the use of innovation providers in the manufacturing sector in the UK.

Future work will focus on validation of the framework and the evaluation process. The scorecards will be presented to the decision makers of seven manufacturing research centers in the UK. After gathering valuable feedback, the scorecards will be modified. Afterwards, the framework will be tested on a short-term projects (at one research center at a time) in order to validate the framework further. This process will highlight which capabilities are used most frequently (or least frequently) at different research centers and also, what are the reasons behind it. Therefore, the validation process will bring an insight into which aspects all seven research centers share, and what should be modified further in order to make the framework applicable (and user friendly) for innovation providers in the manufacturing sector.

References

Alegre, J. and Chiva, R.., Assessing the impact of organizational learning capability on product innovation performance: An empirical test, *Journal of Operations Management*, vol. 28, no. 6, pp 315-326, 2008

Bititci, U., Suwignjo, P. and Carrie, A., Strategy management through quantitative modelling of performance measurement systems, *International Journal of Production Economics*, vol. 69, no.1, pp. 15-22, 2001

Boon-itt, S., Wong, C. Y. and Wong, C. W., Service supply chain management process capabilities: Measurement development. *International Journal of Production Economics*, vol. 193, pp. 1-11, 2017

Booto Ekionea, J.-P., Plaisent, M. and Bernard, P., Developing Knowledge Management Competences as an Organizational Capability for Business Performance, *ECKM 2007 8th European Conference on Knowledge Management 2007* edited by Blanca Martins, CEIB, Spain and Dan Remenyi Trinity College Dublin, Ireland, ISBN: 978-1-62276-524-9, vol.1, pp.131-138, 2007

Covin, J. G., Slevin, D. P. and Schultz, R. L., Implementing strategic missions: Effective strategic, structural and tactical choices, *Journal of Management Studies,* vol. 31, no. 4, pp. 481-506, 1994

Davenport, T. H., Harris, J. G., De Long, D. W. and Jacobson, A. L., Data to Knowledge to Results: Building an Analytic Capability, *California Management Review,* vol. 43, no. 2, pp. 117-138, 2001

Denyer, D. and Tranfield, D. Producing a systematic review. In Buchanan, D. and Bryman, A., The Sage Handbook of Organizational Research Methods, Sage Publications Ltd., London, pp. 671-689, 2009

Drejer, A. and Riis, J. O., Competence development and technology: How learning and technology can be meaningfully integrated. *Technovation,* vol. 19, no. 10, pp. 631-644, 1999

Druilhe, C. and Garnsey, E., Do Academic Spin-Outs Differ and Does it Matter? *The Journal of Technology Transfer,* vol. 29, no. 3-4, pp. 269-285, 2004

Eddleston, K. A., Kellermanns, F. W. and Sarathy, R., Resource Configuration in Family Firms: Linking Resources, Strategic Planning and Technological Opportunities to Performance. *Journal of Management Studies,* vol. 45, no. 1, pp. 26-50, 2008

ElMaraghy, H., Schuh, G., ElMaraghy, W., Piller, F., Schönsleben, P., Tseng, M. and Bernard, A., Product variety management. *CIRP Annals - Manufacturing Technology,* vol. 62, no. 2, pp. 629-652, 2013

Fuchs, P. H., Mifflin, K. E., Miller, D. and Whitney, J. O., Strategic Integration: Competing in the Age of Capabilities. California Management Review. *California Review Management*, vol. 42, no. 3, pp. 118-147, 2000

Harreld, J. B., O'Reilly, C. A. and Tushman, M. L., Dynamic Capabilities at IBM: Driving Strategy into Action. *California Management Review,* vol. 49, no. 4 pp. 185-206, 2007

Hauser, H., Review of the Catapult network Recommendations on the future shape, scope and ambition of the programme, Hauser Report, pp. 7, 12, 2014

Herrmann, P., Evolution of strategic management: The need for new dominant designs. *International Journal of Management Reviews,* vol. 7, no. 2, pp. 111-130, 2005

High Value Manufacturing Catapult, HVM Catapult Introduction, 2018, Available: https://hvm.catapult.org.uk/, April 13, 2018

House of Commons, Science and Technology Committee, Bridging the valley of death: improving commercialisation of research, 8th report of session 2012-2013, Published on March 2013, Written evidence submitted by Rolls-Royce, Manufacturing Capability Readiness Level (MCRL), page Ev183, 2013

Hsu, L.-C. and Wang, C.-H., Clarifying the Effect of Intellectual Capital on Performance: The Mediating Role of Dynamic Capability. *British Journal of Management*, vol. 23, no. 2, pp. 179–205, 2012

Jiang, K., Lepak, D. P., Hu, J. and Bear, J. C., How Does Human Resource Management Influence Organizational Outcomes? A Meta-analytic Investigation of Mediating Mechanisms. *The Academy of Management,* vol. 55, no. 6, pp. 1264-1294, 2012

Kalkan, A., Bozkurt, O. and Arman, M., The impacts of intellectual capital, innovation and organizational strategy on firm performance. *Procedia - Social and Behavioral Sciences*, vol. 150, pp. 700-707, 2014

Kim, D.-Y., Kumar, V. and Kumar, U., Relationship between quality management practices and innovation. *Journal of Operations Management*, vol. 30, no. 4, pp. 295-315, 2012

Kim, Y. and Lee, J., Manufacturing strategy and production systems: An integrated framework. *Journal of Operations Management,* vol. 11, no. 1, pp. 3-15, 1993

Koufteros, X. A., Vonderembse, M. A. and Doll, W. J., Integrated product development practices and competitive capabilities: the effects of uncertainty, equivocality, and platform strategy. *Journal of Operations Management*, vol. 20, no. 4, pp. 331-355, 2002

Kropsu-Vehkapera, H. and Kess, P., Information systems support to the human resource management in universities, *2013 IEEE 11th International Conference on Emerging eLearning Technologies and Applications (ICETA),* DOI: 10.1109/ICETA.2013.6674430, Stara Lesna, Sloviaka, 2013

Kyriakopoulos, K. and De Ruyter, K., Knowledge Stocks and Information Flows in New Product Development. *Journal of Management Studies*, vol. 41, no. 8, pp. 1469–1498, 2004

Lee, H. and Kang, P., Identifying core topics in technology and innovation management studies: a topic model approach. *The Journal of Technology Transfer*, DOI: 10.1007/s10961-017-9561-4, pp. 1-27, 2017

Machado, C. G., de Lima, E. P., da Costa, S. E., Angelis, J. J. and Mattioda, R. A., Framing maturity based on sustainable operations management principles. *International Journal of Production Economics,* vol. 190. pp. 3-21, 2017

Malik, O. R. and Kotabe, M., Dynamic Capabilities, Government Policies, and Performance in Firms from Emerging Economies: Evidence from India and Pakistan. *Journal of Management Studies,* vol. 46, no. 3, pp. 421–450, 2009

McKelvie, A. and Davidsson, P., From Resource Base to Dynamic Capabilities: an Investigation of New Firms. *British Journal of Management*, vol. 20, no. s1, pp. S63–S80, 2009

Mikkola, J. H., Portfolio management of R&D projects: implications for innovation management. *Technovation*, Volume 21, Issue 7, pp. 423-435, 2001

National Aeronautics and Space Administration, NASA (2012). Technology Readiness Levels. NASA website., Available: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html, Accessed February 2017

Nerkar, A. and Paruchuri, S., Evolution of R&D Capabilities: The Role of Knowledge Networks Within a Firm. *Management Science,* vol. 51, no.5, pp. 771-785, 2005

O'Regan, N., Ghobadian, A. and Gallear, D., In search of the drivers of high growth in manufacturing SMEs. *Journal of Operations Management*, vol. 26, no. 1, pp. 30-41, 2006

Paiva, E. L., Roth, A. V. and Fensterseifer, J. E., Organizational knowledge and the manufacturing strategy process: A resource-based view analysis. *Journal of Operations Management*, vol. 26, no. 1, pp. 115-132, 2008

Paladino, A., Investigating the Drivers of Innovation and New Product Success: A Comparison of Strategic orientations. *Journal of Product Innovation Management,* vol. 24, no. 6, pp. 534-553, 2007

Pich, M. T., Loch, C. H. and De Meyer, A., On Uncertainty, Ambiguity, and Complexity in Project Management. *Management Science,* vol. 48, no. 8, pp. 1008-1023, 2002

Raul, C. O. and Stylianos, K., A Theoretical Framework for Managing the New Product Development Portfolio: When and How to Use Strategic Buckets. *Management Science,* vol. 54 no. 5, pp. 907-921, 2008

Saemundsson, R. J. and Candi, M., Absorptive capacity and the identification of opportunities in new technology-based firms. *Journal of Operations Management,* vol. 64-65, pp. 43-49, 2017

Slater, S. F., Mohr, J. J. and Sengupta, S., Radical Product Innovation Capability: Literature Review, Synthesis, and Illustrative Research Propositions. *Journal of Product Innovation Management*, vol. 31, no. 3, pp. 552-566, 2014

Soo, C., Devinney, T., Midgley, D. and Deering, A., Knowledge Management: Philosophy, Processes, and Pitfalls. *California Management Review,* vol. 44, no. 4, pp. 129-150, 2002

Srivastava, M. K. and Gnyawali, D. R., When Do Relational Resources Matter? Leveraging Portfolio Technological Resources for Breakthrough Innovation. *The Academy of Management*, vol. 54, no. 4, pp. 797-810, 2010

St John, C. H., Cannon, A. R. and Pouder, R. W., Change drivers in the new millennium: implications for manufacturing strategy research. *Journal of Operations Management,* vol. 19, no. 2, pp. 143-160, 2001

Thompson, M. and Walsham, G., Placing Knowledge Management in Context. *Journal of Management Studies*, vol. 41, no. 5, pp. 725–747, 2004

Transfield, D., Denyer, D. and Smart, P., Towards a methodology for developing evidence-informed management knowledge by means of systematic Review. *British Journal of Management,* vol. 14, no. 3, pp. 207-222, 2003

Tu, Q., Vonderembse, M. A., Ragu-Nathan, T. S. and Sharkey, T. W., Absorptive capacity: Enhancing the assimilation of time-based manufacturing practices. *Journal of Operations Management*, 692-710, 2006

Uflewska, O.,Wong, T.C. and Ward, M., Development of technology maturity framework in managing manufacturing improvement for innovation providers, *Proceedings of 24th Innovation and Product Development Management Conference*, Reykjavik, Iceland, June 2017

Wang, C. L. and Ahmed, P. K., Dynamic capabilities: A review and research agenda. *International Journal of Management Reviews,* vol. 9, no. 1, pp. 31-51, 2007

Ward, Michael J., Halliday, Steven T. and Foden, J., A readiness level approach to manufacturing technology development in the aerospace sector: an industrial approach. *Proceedings of Institution of Mechanical Engineers, Part B: J. Engineering Manufacture*, vol. 226, no. 3, pp. 547-552, 2012

Wetzstein, A., Hartmann, E., Benton, W. and Hohenstein, N.-O., A systematic assessment of supplier selection literature - State-of-the-art and future scope. *International Journal of Production Economics,* vol. 182, pp. 304-323, 2016

Zhang, Q., Vonderembse, M. A. and Lim, J.-S., Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management,* vol. 21, no. 2, pp. 173-191, 2003

Biographies

Olga Uflewska is an Engineering Doctorate candidate in the Department of Design, Manufacture and Engineering Management at University of Strathclyde, Glasgow, UK and she works closely with Advanced Forming Research Centre. She holds a Bachelor of Science degree in Mathematics from University of Glasgow and a Master of Science degree in Sustainable Engineering from University of Strathclyde. Her research interests include decision making in manufacturing, technology capability management and operations management. She is a member of The Institution of Engineering and Technology.

T.C. Wong received the B.Eng. degree in Industrial Engineering and the M.Phil. and Ph.D. degrees in Operations Research from the University of Hong Kong, Pokfulam, Hong Kong. He is a member of IEEE and Senior Member of Hong Kong Society for Quality (HKSQ). His research areas include evolutionary algorithms, computational modelling and optimization, production scheduling, and decision-making. Prior to joining the University of Strathclyde as Lecturer in 2014, he worked at the City University of Hong Kong for more than 5 years. He is a reviewer of several International Journals such as International Journal of Production Research, IIE Transactions, Decision Support Systems, Computers & Industrial Engineering, etc.

Michael Ward is Research Director at the AFRC. He has spent a quarter of a century in the field of manufacturing innovation. This has included several years at Rolls-Royce, where he had roles in capability acquisition, the Trent 1000 programme, and process modelling. In his early career he worked with ABB Daimler Benz Transportation in the petrochemical processing industry.